

Using high-energy x-rays to study structure and properties of metallic glasses and metallic-glass-matrix composites

Todd C. Hufnagel

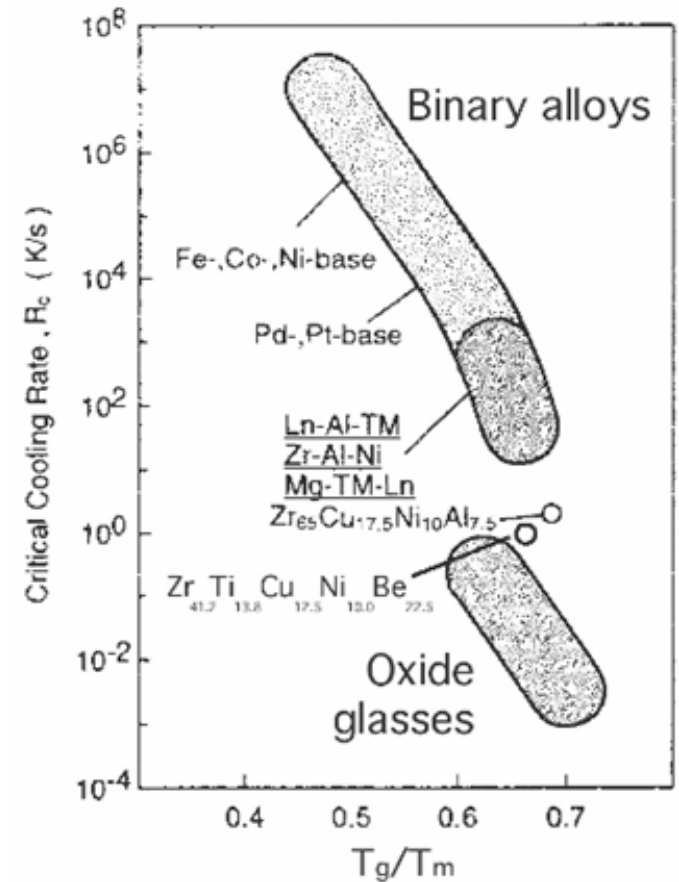
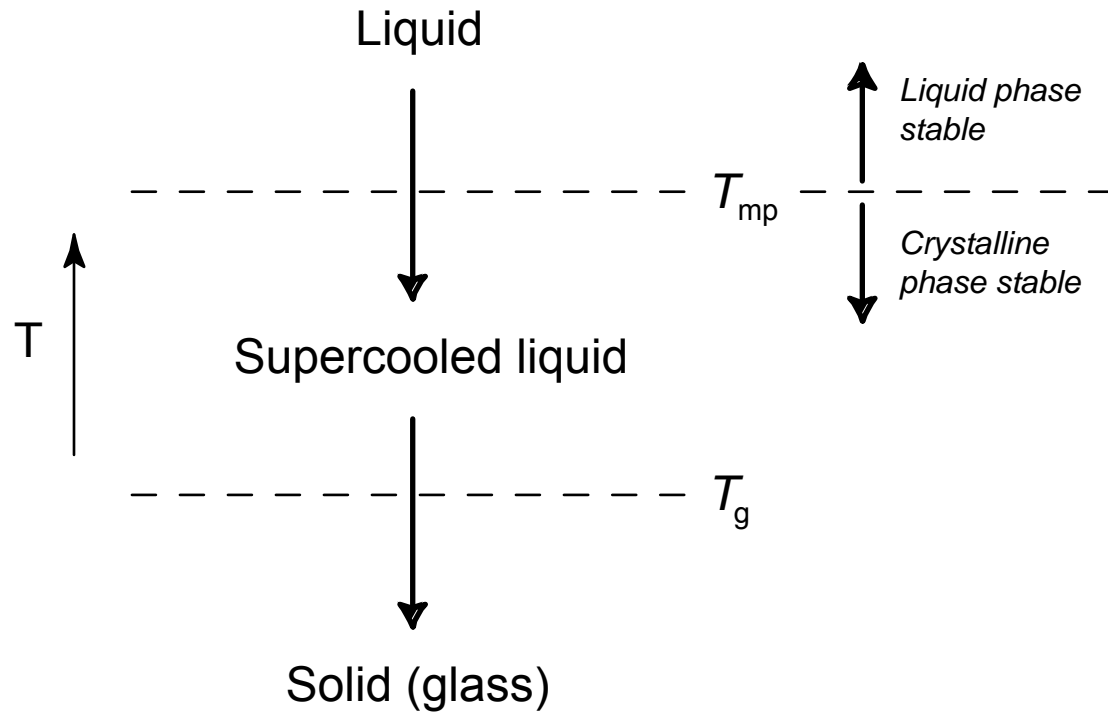
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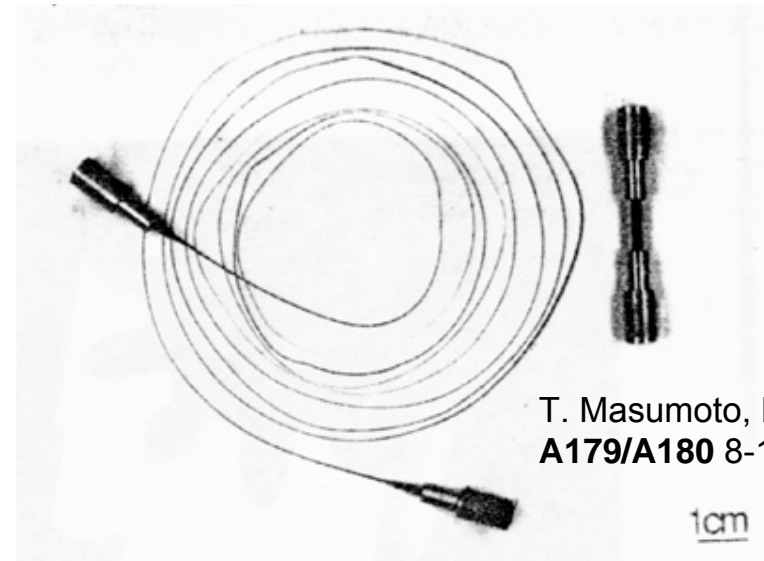
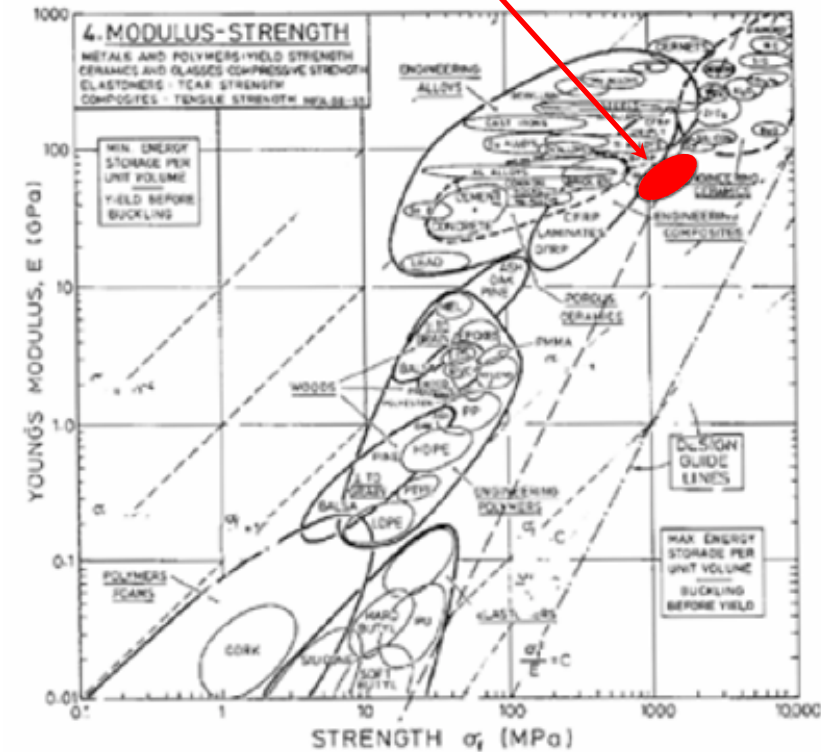
Outline

- Brief review of recent developments in metallic glasses
- Examples:
 - High-energy x-ray scattering: Micromechanics of deformation of metallic-glass-matrix composites
 - Resonant x-ray scattering: Structure of metallic glasses
- Opportunities for using high-energy x-rays to study amorphous alloys



Adapted from T. Masumoto,
Mat. Sci. Eng. **A179/A180** 8-16 (1994)

High strength
and resilience

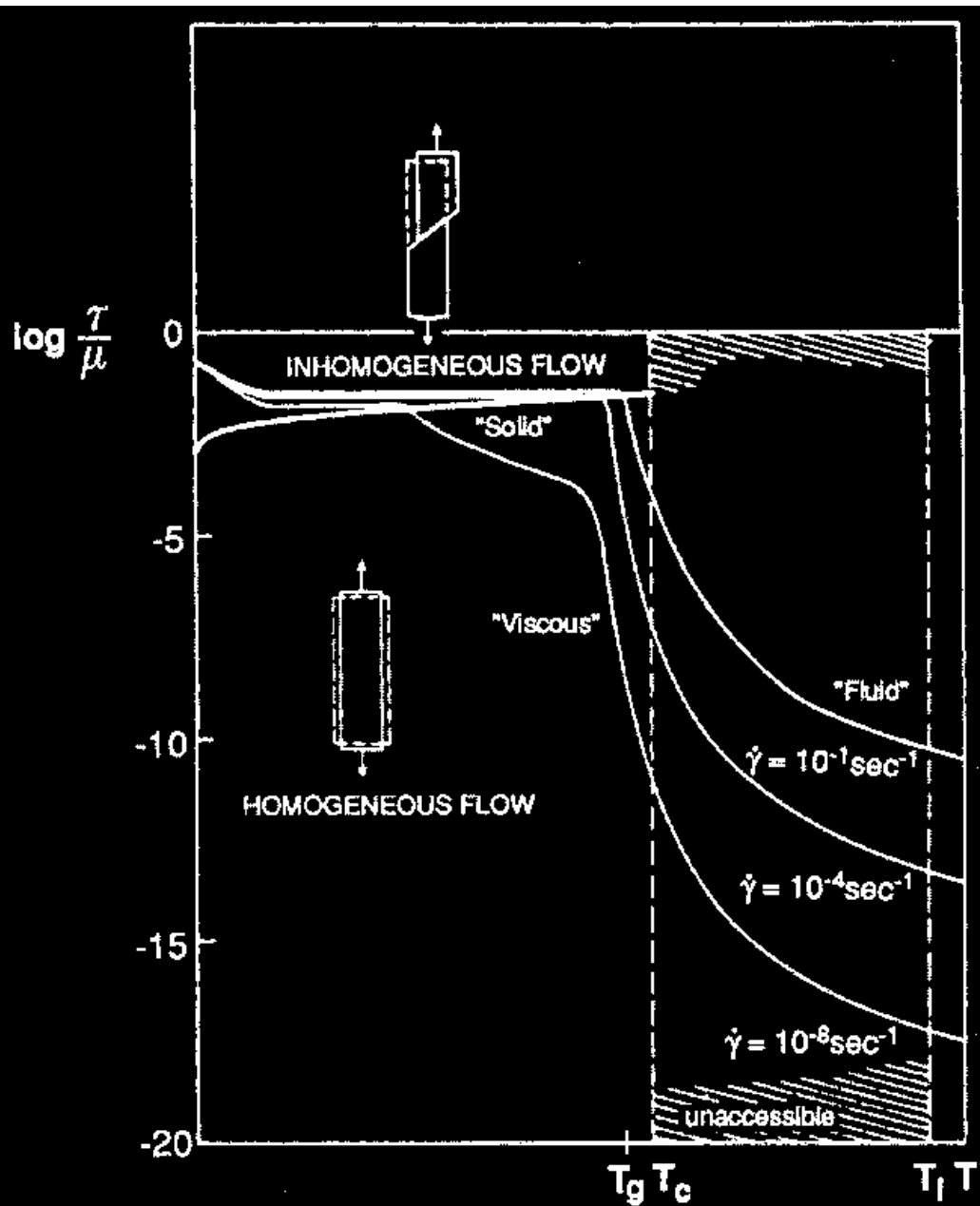


T. Masumoto, Mat. Sci. Eng.
A179/A180 8-16 (1994)

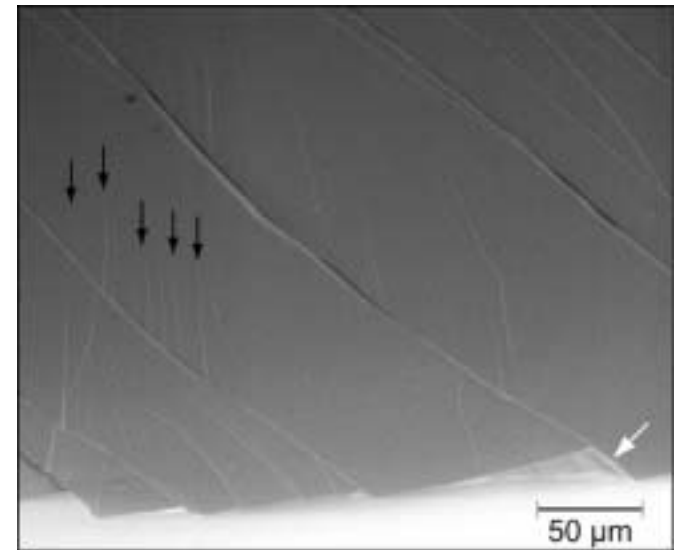
Processing flexibility



www.liquidmetal.com



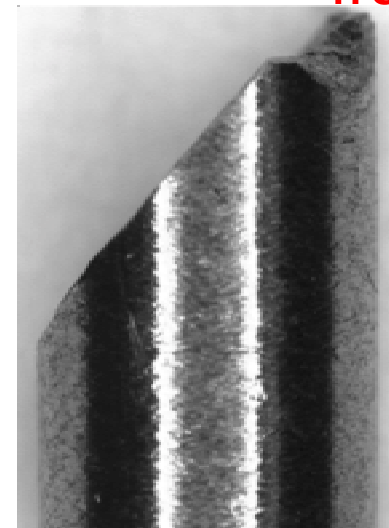
F. Spaepen *Acta Met.* **25**, 407 (1977)

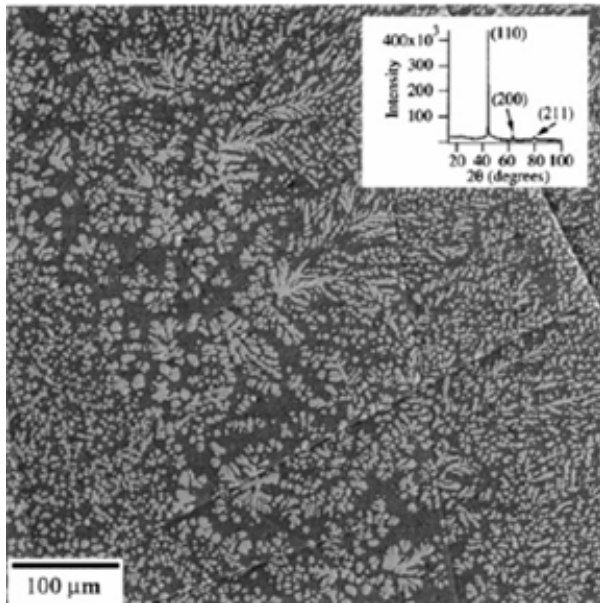


T. C. Hufnagel *et al. Scripta Mat.* **12**, 1071 (2000)

1 mm

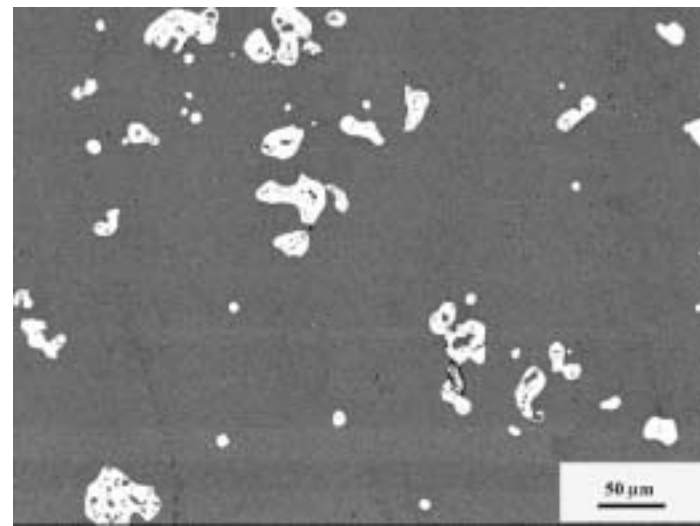
"Brittle"
fracture



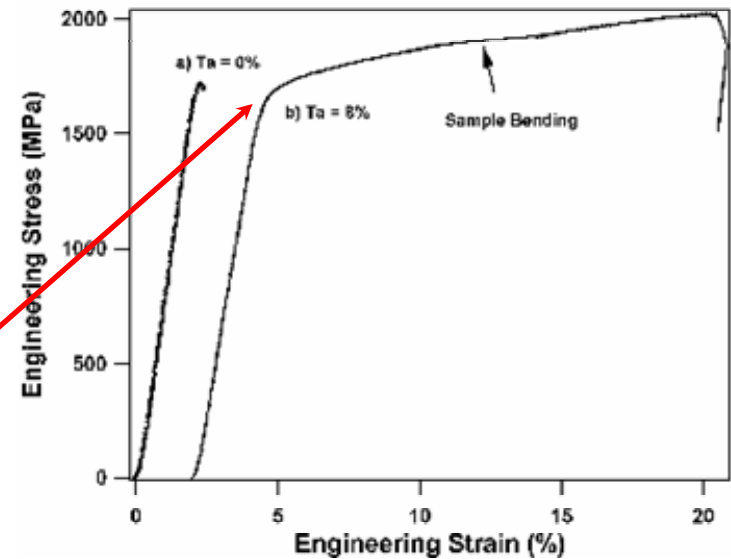


Composite formed by precipitation of dendritic ductile intermetallic in metallic glass matrix

C. C. Hays *et al.* *Phys. Rev. Lett.* **84**, 2901 (2000)



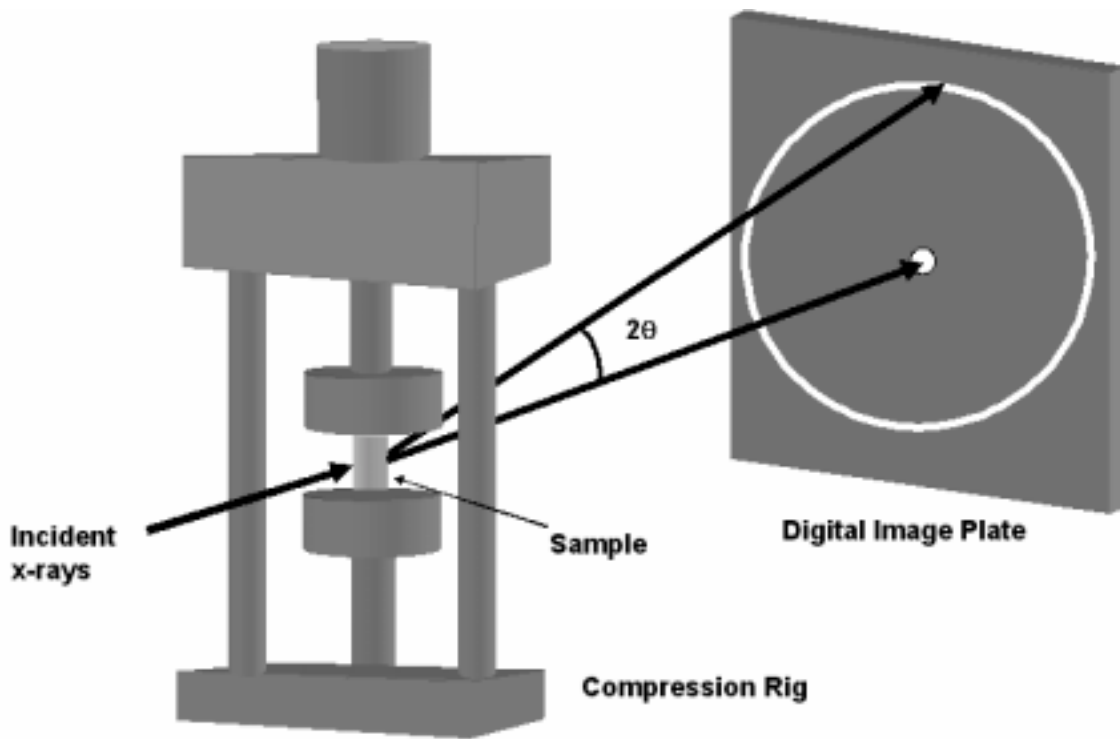
Metallic-glass-matrix composite formed by precipitation of high melting-point phase prior to casting of final ingot



Yield stress apparently not affected by presence of particles (~1700 MPa)

C. Fan, R. T. Ott, and T. C. Hufnagel, *Appl. Phys. Lett.* **81**, 1020 (2002)

R. T. Ott *et al.*, *Mat. Res. Soc. Symp. Proc.* **806**, 361 (2004).



APS beamline 1-ID

$E = 80.72 \text{ keV}$

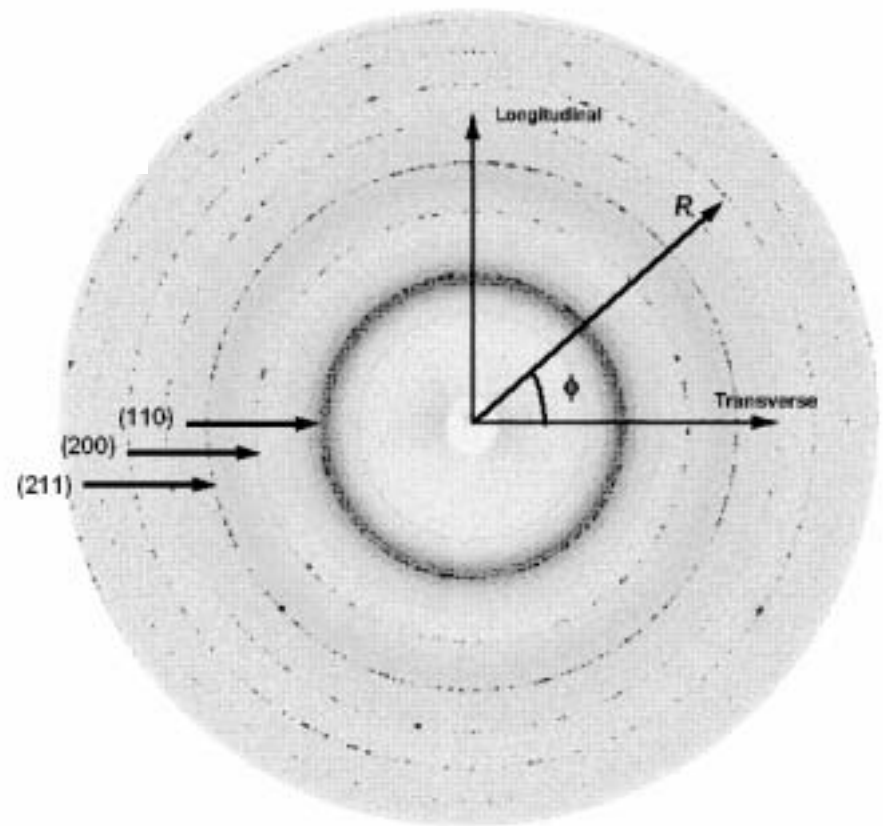
Spot size $150 \times 150 \text{ } \mu\text{m}$

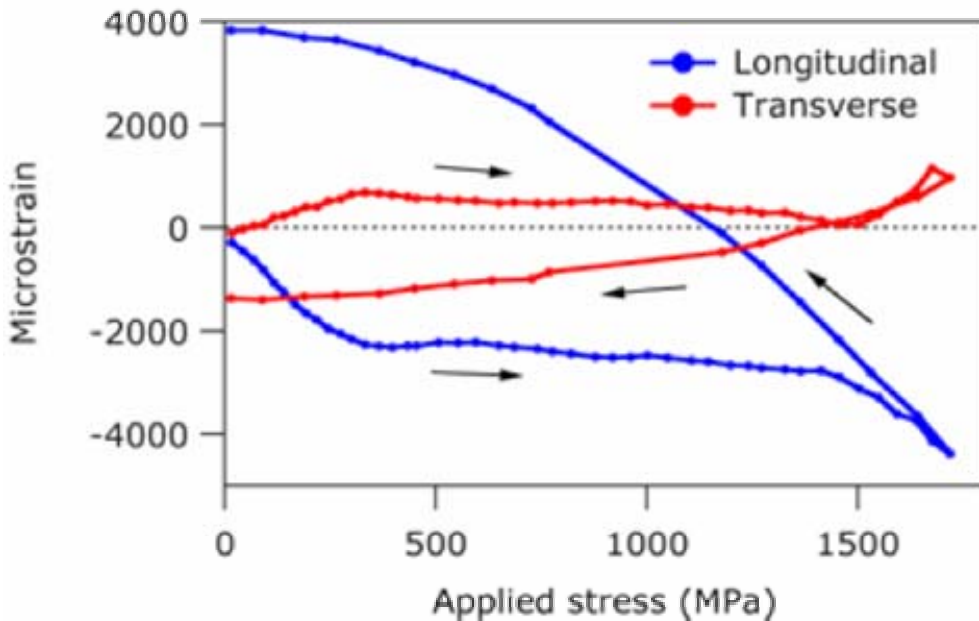
Camera length 975 mm

MAR 345 digital image plate

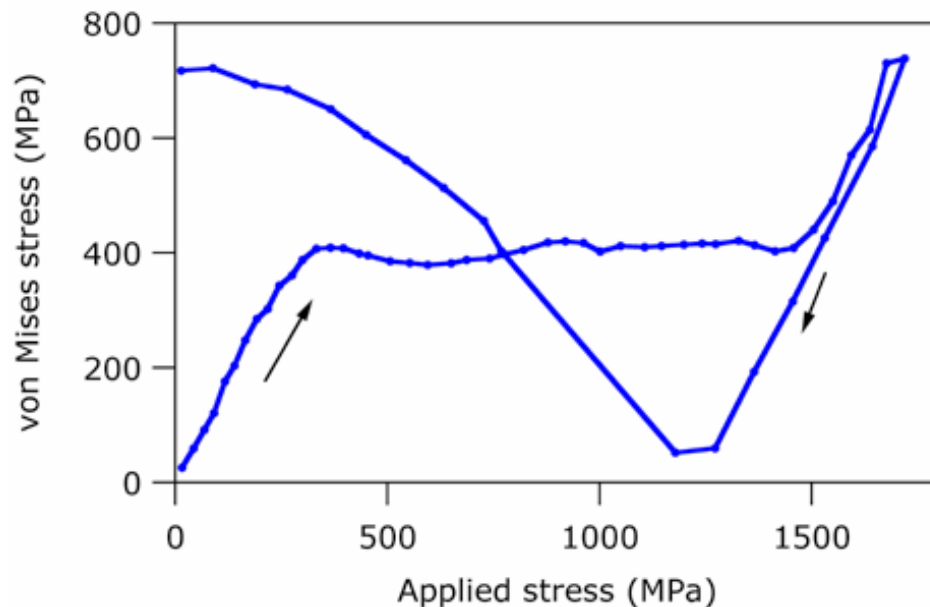
Specimen $L = 6 \text{ mm}$, $D = 3 \text{ mm}$

Uniaxial strain distorts “powder” rings into ellipses; get principal strains by fitting entire ellipse.





Strains in the Ta particles as a function of applied stress. The particles experience elastic deformation followed by yield at approximately 350 MPa. The increase in strain at ~1400 MPa is due to local yielding of the metallic glass matrix. Notice that the particles yield again in tension upon unloading.

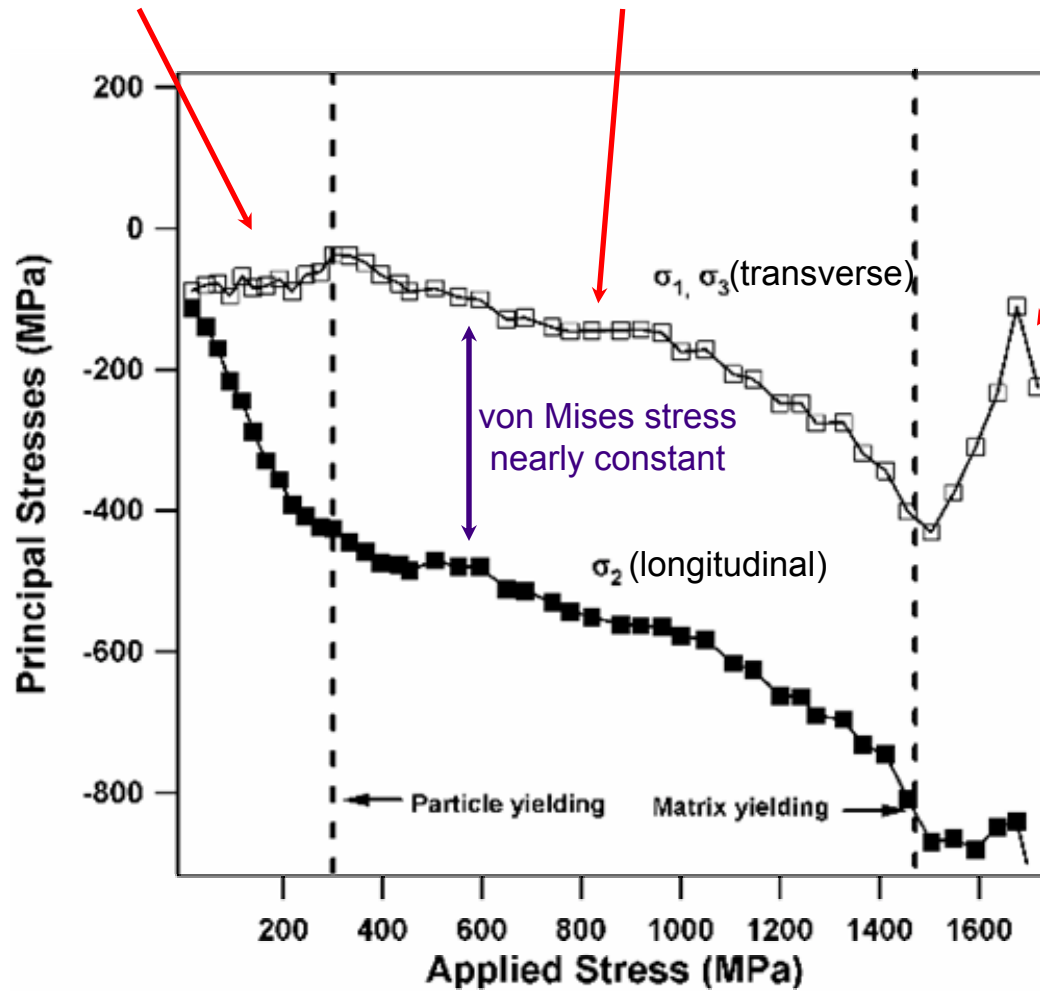


The von Mises effective stress calculated from the measured principal strains. The initial plastic flow of the particles occurs with little strain hardening due to the constraint of the matrix. When local yielding of the matrix occurs at ~1400 MPa, the particles strain harden considerably.

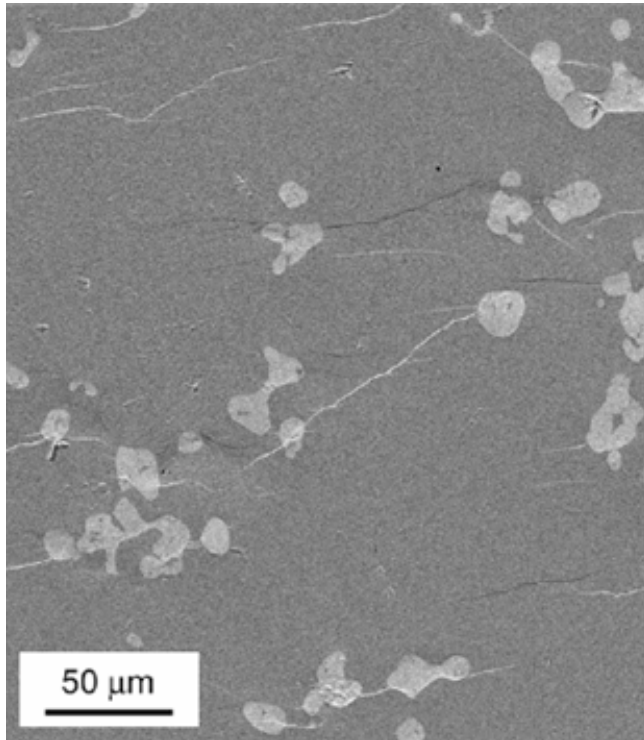
$v(\text{matrix})=0.38$
>
 $v(\text{particles})=0.34$

$v(\text{matrix})=0.38$
<
 $v(\text{particles})=0.50$ (effective)

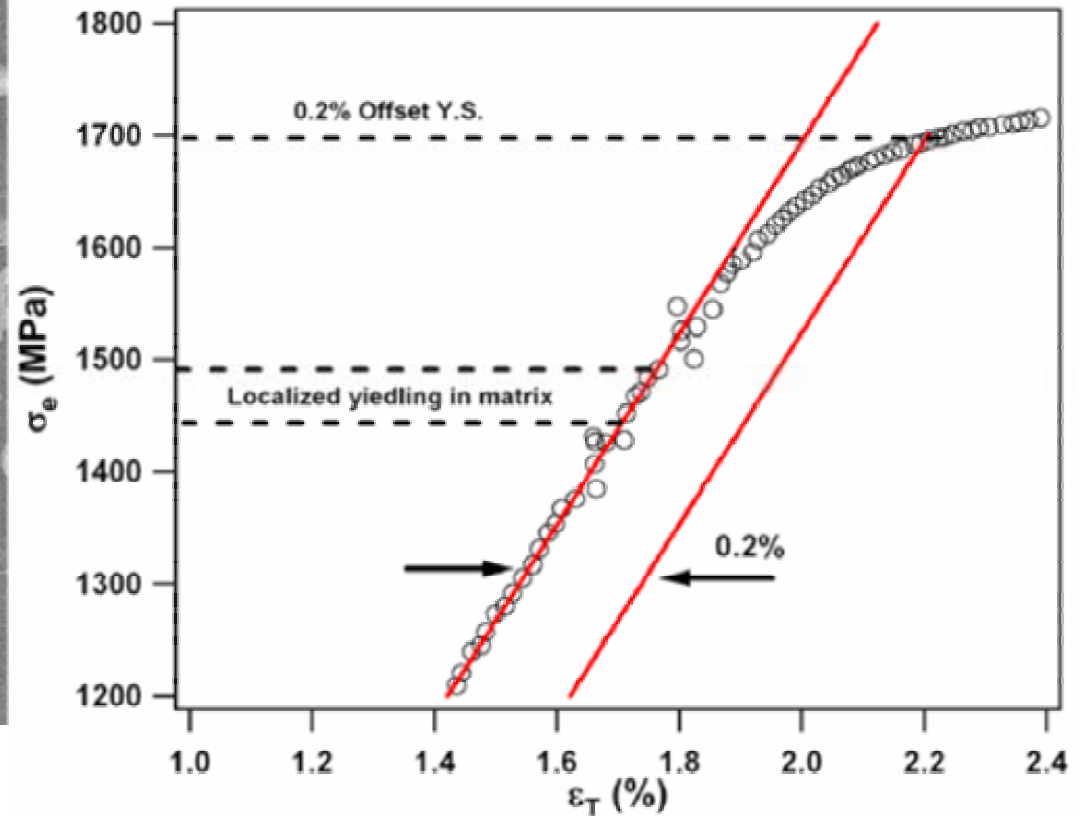
$v(\text{matrix})=v(\text{particles})=0.50$ (effective)



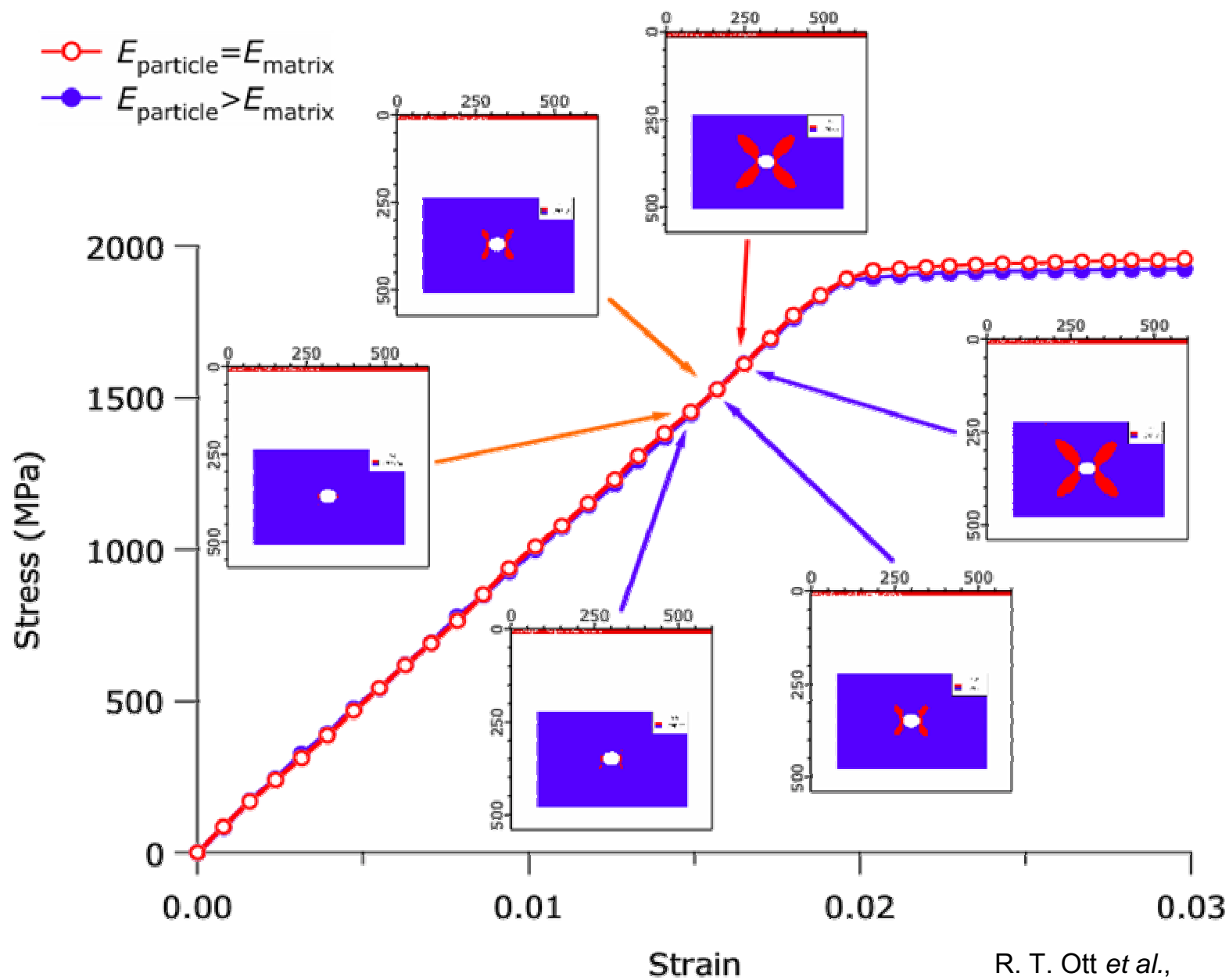
R. T. Ott *et al.*,
(unpublished)



Loaded to 1700 MPa



- The particles yield at ~400 MPa
- Local yielding of matrix occurs at ~1450 MPa
- Large-scale yielding (0.2% offset) occurs at higher stresses, ~1700 MPa



R. T. Ott *et al.*,
(unpublished)

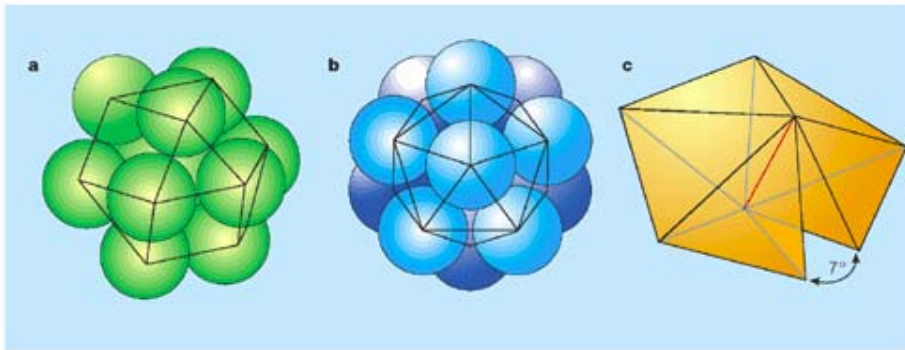
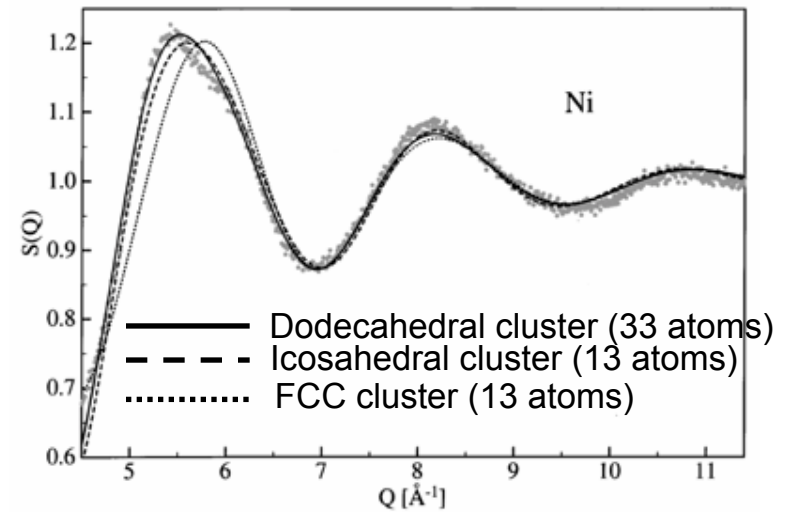
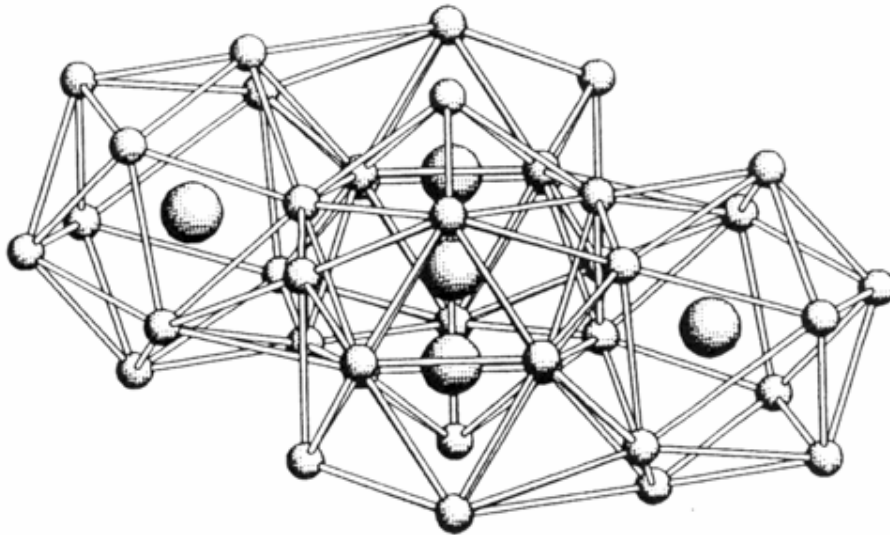


Figure 1 Structural building blocks. Twelve atoms surrounding a central one can form: a, a cuboctahedral arrangement, as in a face-centred cubic crystal; or b, an icosahedral arrangement, as found in a liquid. c, A ring formed by five tetrahedra sharing an edge, leaving a gap with an angle of 7° . The work of Reichert *et al.*¹ suggests that five-fold symmetry is ubiquitous in the structure of liquids.

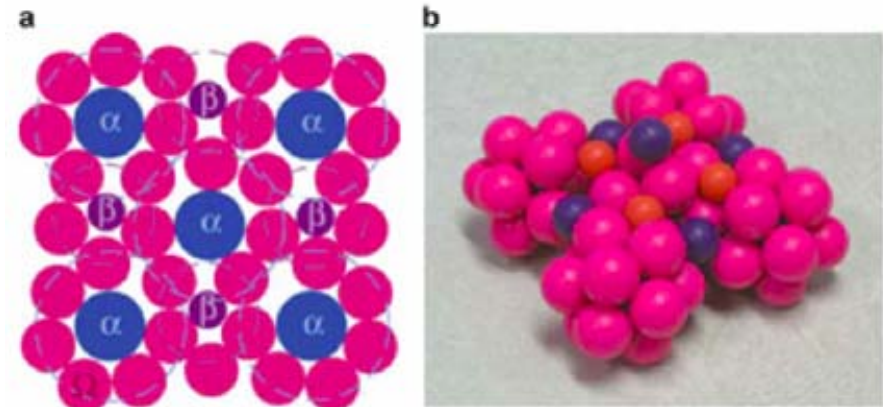
F. Spaepen, *Nature* **408**, 781 (2000)



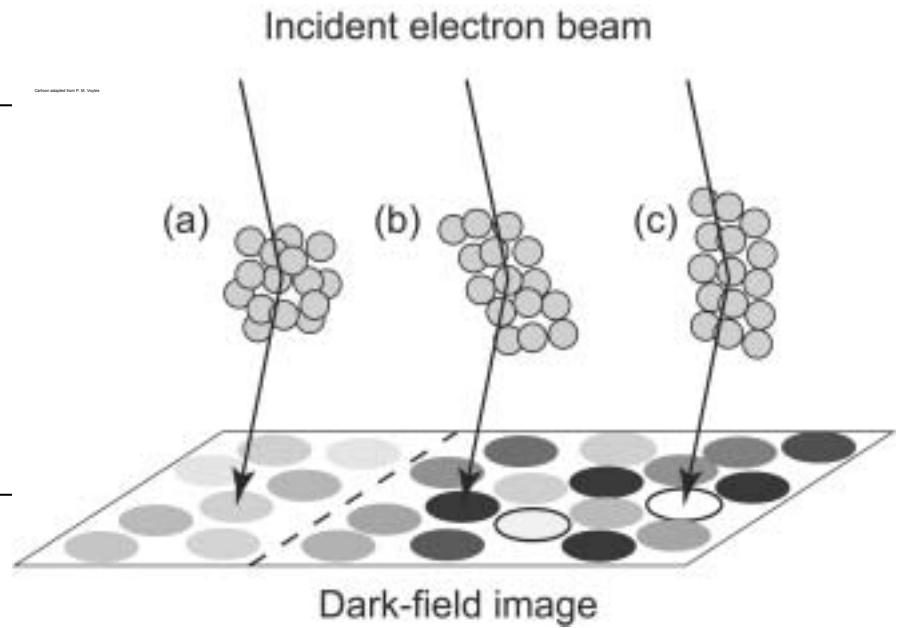
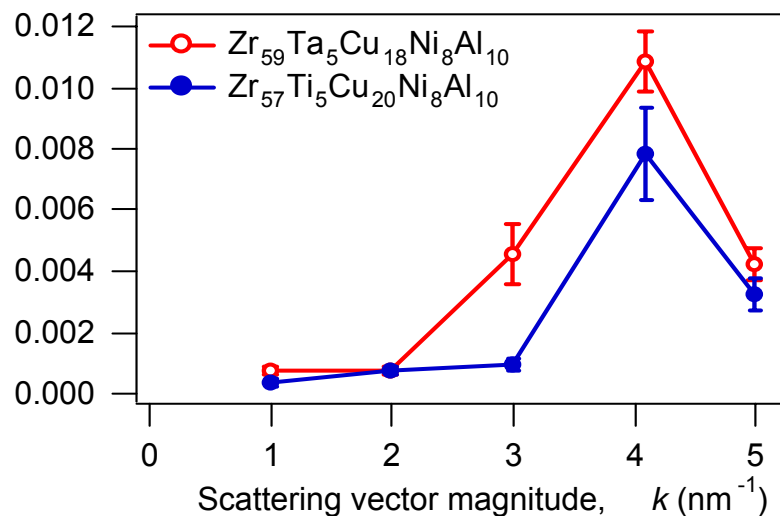
T. Schenk *et al. Phys. Rev. Lett.* **89**, 075507 (2002)

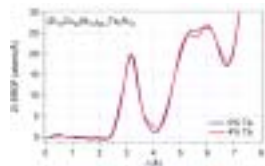


L. Cervinka, *J. Non-Cryst. Sol.* **156-158**, 94 (1993)

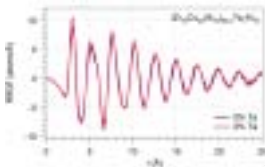


D. B. Miracle *Nature Mat.* (2004) (in press)



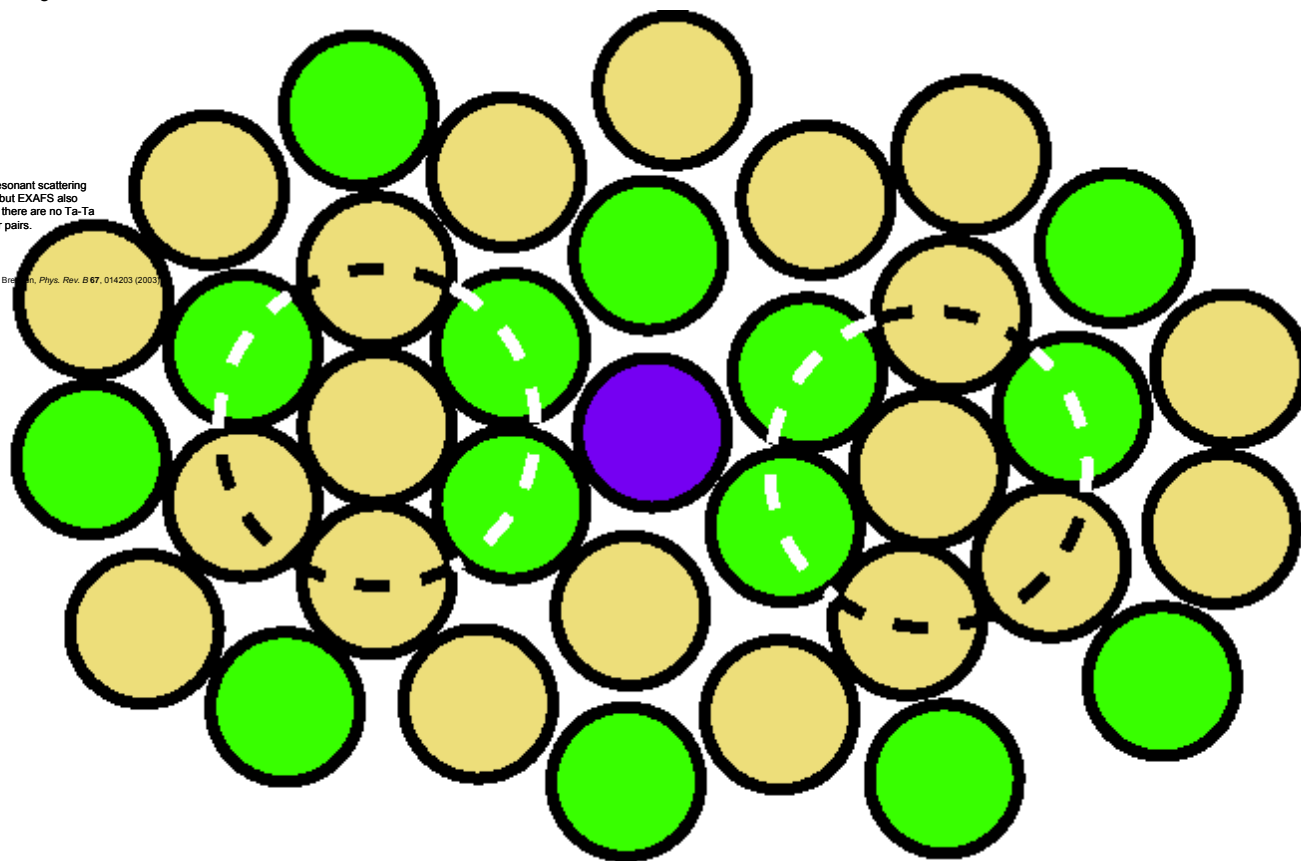


Zr-based glasses
containing Ta

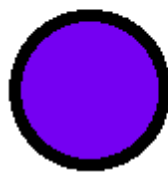


Ta $L_{2,3}$ edge resonant scattering
inconclusive, but EXAFS also
suggests that there are no Ta-Ta
near-neighbor pairs.

T. C. Huftagel and S. Brennan, *Phys. Rev. B* 67, 014203 (2003).



Zr



Ta



Cu, Ni, or Al

Opportunities for high-energy x-rays

- Continued *in situ* studies of deformation of composites (particle size, vol. fraction, nature of reinforcement, single particle studies)
- Study deformation of single-phase glasses (homogeneous deformation, or inhomogeneous deformation in constrained loading)
- Studies of phase transformations in the bulk (solidification, crystallization, spinodal decomposition)
- Access to higher-energy absorption edges (resonant scattering, EXAFS, XANES)
- Fluctuation x-ray microscopy (but need focusing optics for high-energy x-rays)